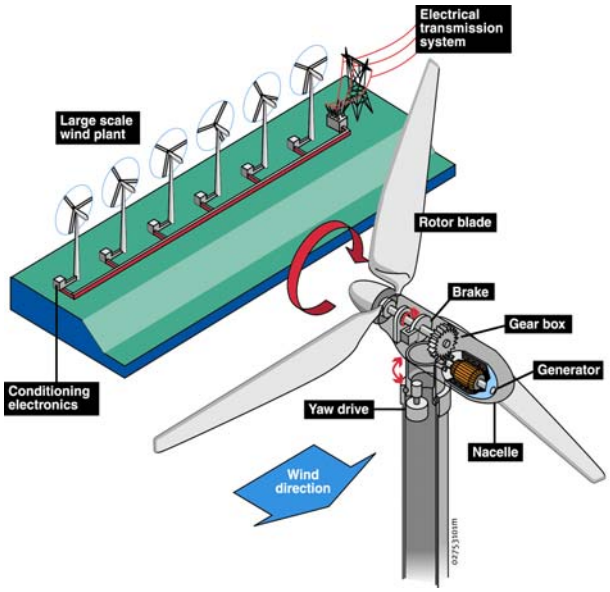
2.3 RENEWABLE ENERGY AND FUELS

2.3.1 WIND ENERGY

Technology Description

Wind turbine technology converts the kinetic energy in wind to electricity. Grid-connected wind power reduces greenhouse gas emissions by displacing the need for natural gas and coal-fired generation. Village and off-grid applications are important for displacing diesel generation and for improving quality of life, especially in developing countries.



System Concepts

- Most modern wind turbines operate using aerodynamic lift generated by airfoil-type blades, yielding much higher efficiency than traditional windmills that relied on wind "pushing" the blades. Lifting forces spin the blades, driving a generator that produces electric power in proportion to wind speed. Turbines either rotate at constant speed and directly link to the grid, or at variable speed for better performance, using a power electronics system for grid connection. Utility-scale turbines for wind plants range in size up to several megawatts, and smaller turbines (under 100 kilowatts) serve a range of distributed, remote, and stand-alone power applications.

Representative Technologies

- The most common machine configuration is a three-bladed wind turbine, which operates "upwind" of the tower, with the blades facing into the wind. To improve the cost-effectiveness of wind turbines, technology advances are being made for rotors and controls, drive trains, towers, manufacturing methods, site-tailored designs, and offshore and onshore foundations.

Technology Status/Applications

- In the United States, the wind energy capacity tripled from 1,600 MW in 1994 to more than 6,700 MW by the end of 2004 – enough to serve more than 1.6 million households.
- Current performance is characterized by levelized costs of 4-6¢/kWh (depending on resource quality and financing terms), capacity factors of 30%-50%, availability of 95-98%, total installed costs of approximately $800-$1,100/kW, and efficiencies of 65%-75% of theoretical (Betz limit) maximum.

Current Research, Development, and Demonstration

RD&D Goals

- By 2007: For distributed wind turbines under 100 kw, achieve a power production cost of 10-15¢/kWh in Class 3 winds.
- By 2012: For larger systems greater than 100 kw, the goal is to achieve a power production cost of 3¢/kWh for onshore at sites with average wind speeds of 13 mph (wind Class 4), and 5¢/kWh at offshore sites with average wind speeds of 13 mph (wind Class 4).

RD&D Challenges

- Developing wind technology that will be economically competitive at low (13 mph) wind-speed sites requires optimizing increasingly large turbine designs in a fatigue-driven environment with minimal or no component replacements, requiring improved knowledge of wind inflow, aerodynamics, structural dynamics and materials, and optimal control of turbines and wind farms.
- Developing information and strategies to facilitate and optimize integration of wind power into electric grid systems.
- Developing offshore wind technology to take advantage of the immense wind resources in shallow and deep waters of U.S. coastal areas and the Great Lakes near large energy markets.
- Conducting analysis and R&D to explore the role of wind power in the production of hydrogen, in both large-scale and distributed systems.

RD&D Activities

- Core and university research: wind characteristics and forecasting, aerodynamics, structural dynamics and fatigue, and control systems for turbines and wind farms.
- Turbine research: cost-shared design and testing of next-generation utility-grade technology for low wind-speed sites, performance verification of onshore and offshore prototypes, development of advanced small turbines for distributed power applications, and component and system testing at the National Wind Technology Center (NWTC).
- Cooperative research and testing: collection of wind turbine-performance data, power-systems integration, resource assessment, industry technical support, participation in international standards development, wind turbine-certification assistance, and regionally targeted outreach.

Recent Progress

- In 1989, the wind program set a goal of 5¢/kWh by 1995 and 4¢/kWh by 2000 for sites with average wind speeds of 16 mph. The program and the wind industry met the goals as part of dramatic cost reductions from 25¢-50¢/kWh in the early 1980s to 4¢-6¢/kWh today
- Wind power is the world's fastest-growing energy source. In the past decade, the global wind energy capacity has increased ten fold from 3,500 MW in 1994 to almost 50,000 MW by the end of 2004. During 2004, nearly 8,000 MW of new capacity was added worldwide.
- Domestic public interest in environmentally responsible electric generation technology is reflected by new state energy policies and in the success of "green marketing" of wind power throughout the country.
- The National Wind Technology Center (operated by the National Renewable Energy Laboratory in Golden, Colorado) is recognized as a world-class center for wind energy R&D and has many facilities – such as blade structural test stands and a large gearbox test stand – not otherwise available to the domestic industry.

Commercialization and Deployment Activities

- Installed wind capacity in the United States expanded from 2,554 MW to 6,740 MW during the period of 2000 to 2004.
- California has the greatest installed wind capacity, followed by Texas, Iowa, Minnesota, Oregon, Washington, Wyoming, New Mexico, Colorado, and Oklahoma.
- Wind technology is competitive today in bulk power markets with support from the production tax credit – and in high-value niche applications or markets that recognize non-cost attributes. Its competitiveness is affected by policies regarding ancillary services and transmission and distribution regulations. Continued

cost reductions from low wind-speed technologies will increase the resource areas available for wind development by 20-fold and move wind generation five times closer to major load centers.

- The principal markets for wind energy are substitution for new natural gas combined-cycle plants or displacement of fuel from existing plants, and replacement of coal-generated power plants. Emerging markets for wind energy include providing energy for water purification, irrigation, and hydrogen production.
- Utility restructuring is a critical challenge to increased deployment in the near term because it emphasizes short-term, low-capital-cost alternatives and lacks public policy to support deployment of sustainable technologies such as wind energy.
- In the United States, the wind industry is thinly capitalized, except for General Electric Wind Energy, which recently acquired wind technology and manufacturing assets in April 2002. About six manufacturers and six to 10 developers characterize the U.S. industry.
- In Europe, there are about 10 turbine manufacturers and about 20 to 30 project developers. European manufacturers have established North American manufacturing facilities and are actively participating in the U.S. market.

- Initial lower levels of wind deployment (up to 15%-20% of the total U.S. electric system capacity) are not expected to introduce significant grid reliability issues. Since the wind resource is variable, intensive use of this technology at larger penetrations may require modification to system operations or ancillary services. Transmission infrastructure upgrades and expansion will be required for large penetrations of onshore wind turbines. However, offshore resources are located close to major load centers.
- Small wind turbines (100 kW and smaller) for distributed and residential grid-connected applications are being used to harness the Nation's abundant wind resources and defer impacts to the long-distance transmission market. Key market drivers include state renewable portfolio standards, incentive programs, and demand for community-owned wind applications.